



# *Liquid Salt-Cooled VHTR Analysis at INL*

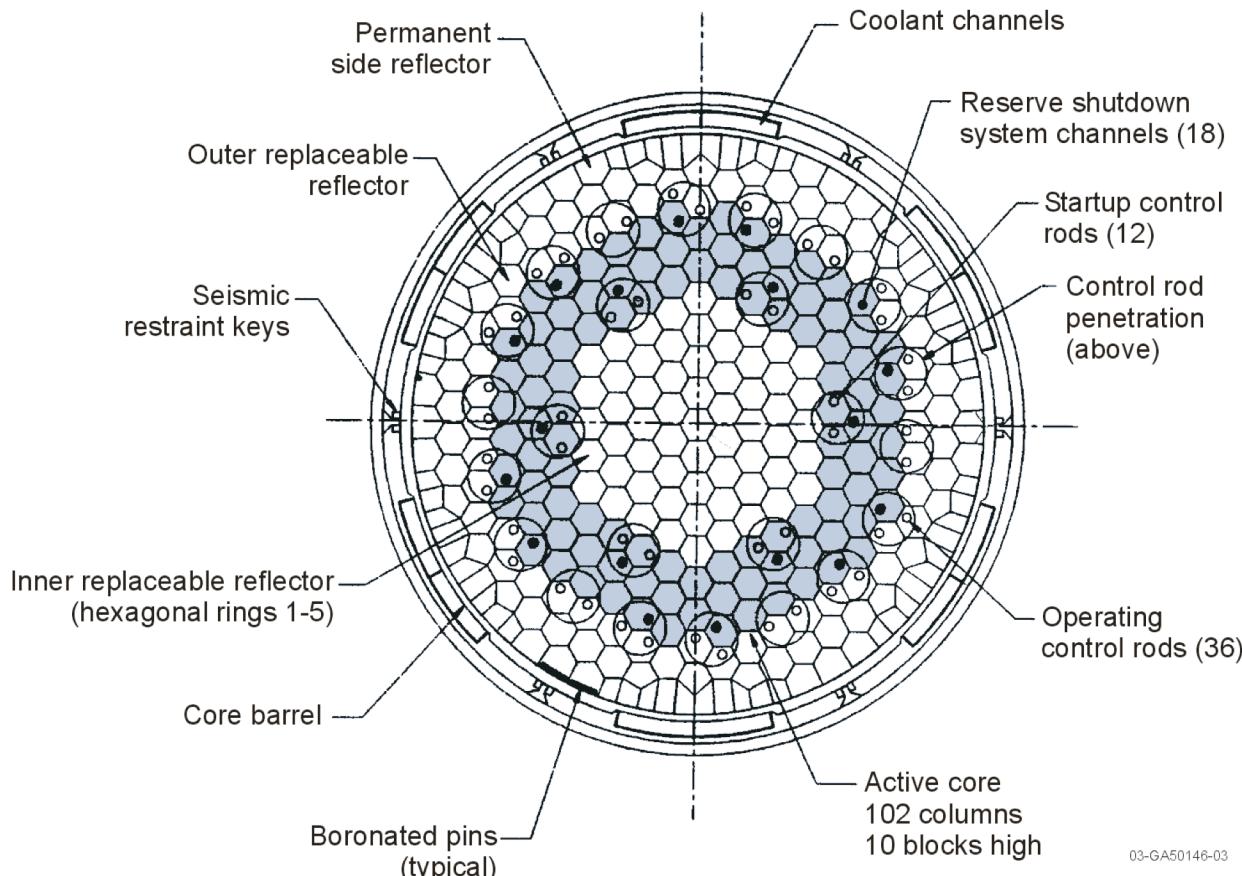
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*Joint AFCI/Gen-IV Physics Working Group  
Salt Lake City Marriott Downtown, UT*

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Idaho National Laboratory***

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# General Atomics GT-MHR He-VHTR Prismatic Reference Design



- **600 MW(th) total power**
- **Annular, 3-ring active core**
- **Prismatic block**
- **102 fuel block columns**
- **10 blocks per column**
- **6.5 MW/m<sup>3</sup> power density**
- **Helium coolant**
- **TRISO-coated particle fuel**
- **1.58-cm dia. coolant ch**
- **6.66-meter core diameter**

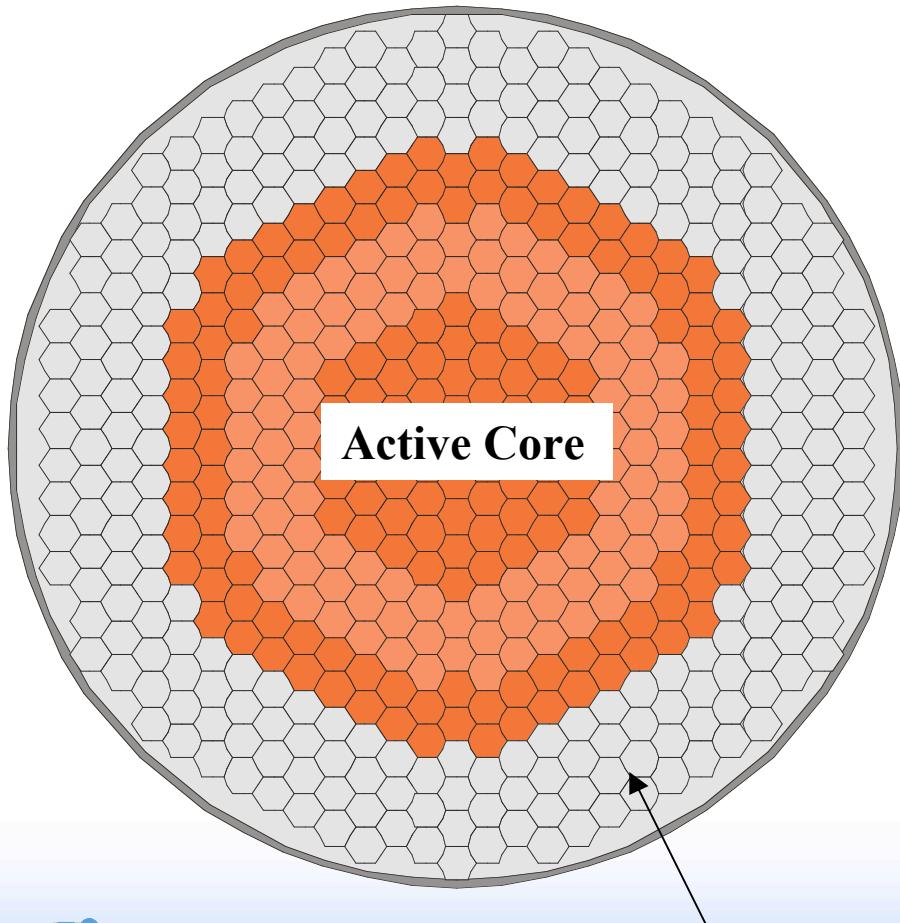
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# *Liquid Salt-cooled VHTR* *Reference Core Design*

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- 2400 MW(th) total power
- Non-annular, 10-ring active core
- Prismatic block
- 265 fuel block columns
- 10 blocks per column
- 10 MW/m<sup>3</sup> power density
- FLIBE coolant (2LiF-BeF<sub>2</sub>) with 99.995% <sup>7</sup>Li enrichment
- TRISO-coated particle fuel
- 0.953 cm dia. coolant channel
- 9-meter core diameter

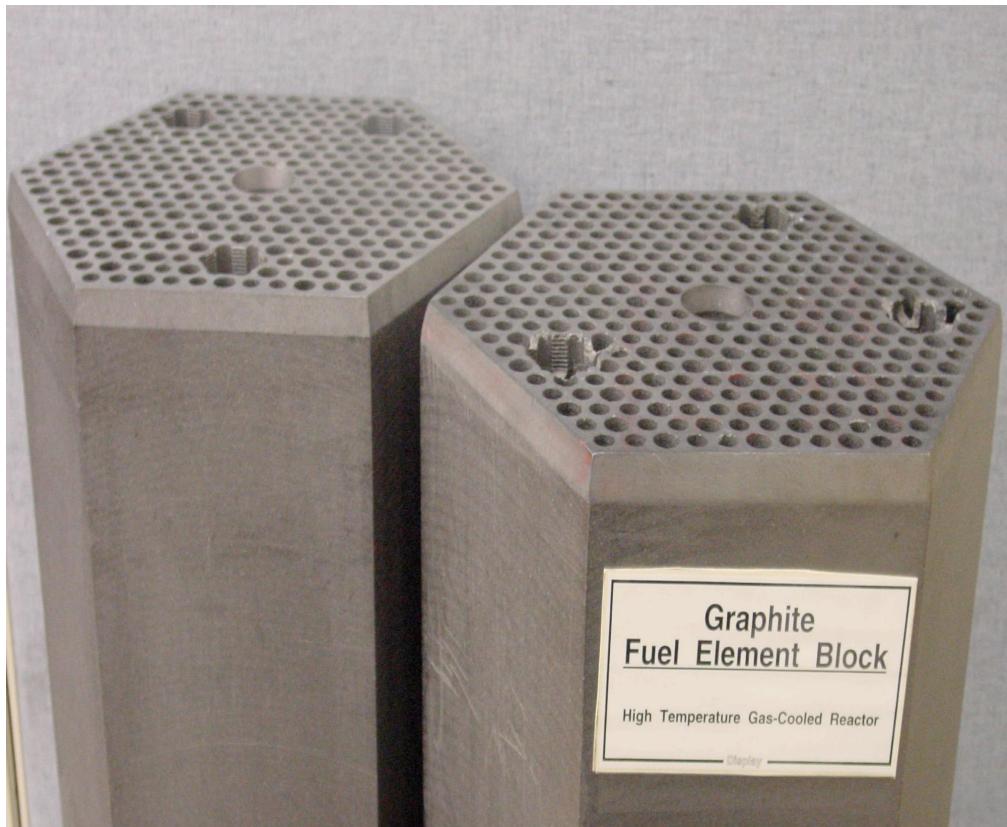


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Outer graphite reflector

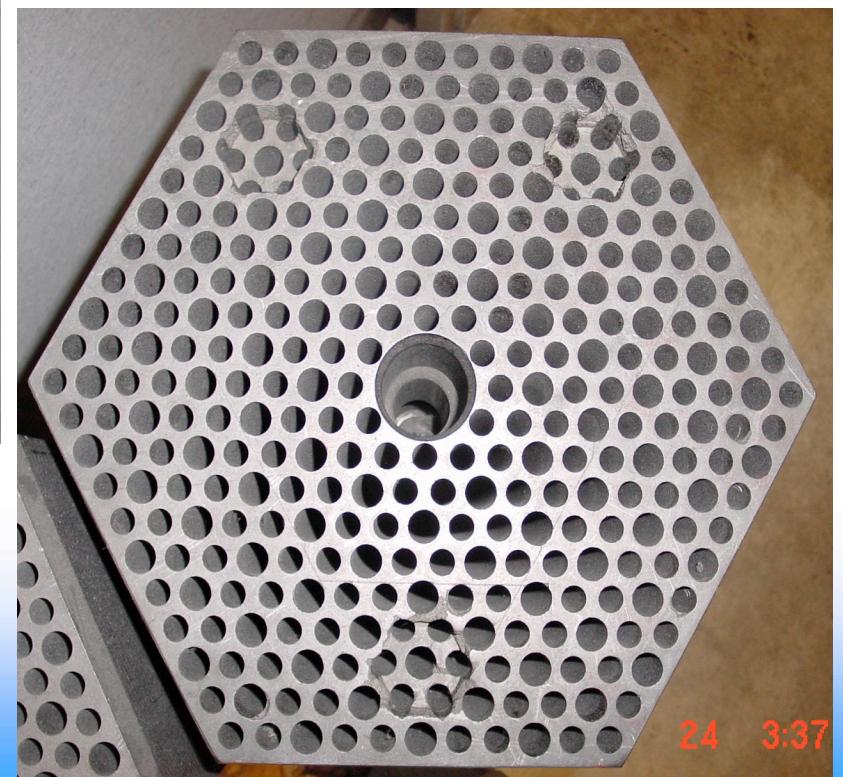
## *Current Prismatic Fuel Block*

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### Characteristics:

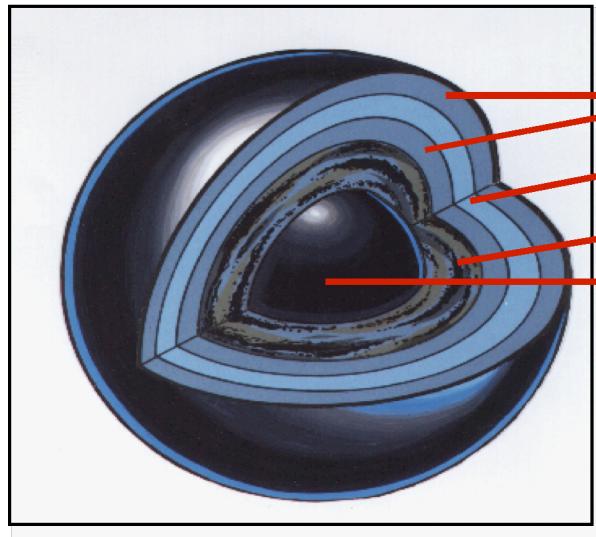
- Hex graphite block
- 79.3-cm length (31.22")
- 36-cm flat-to-flat (14.172")
- 210 fuel rods
- 108 coolant channels
- Fuel compacts



### Fort St. Vrain Standard Fuel Block



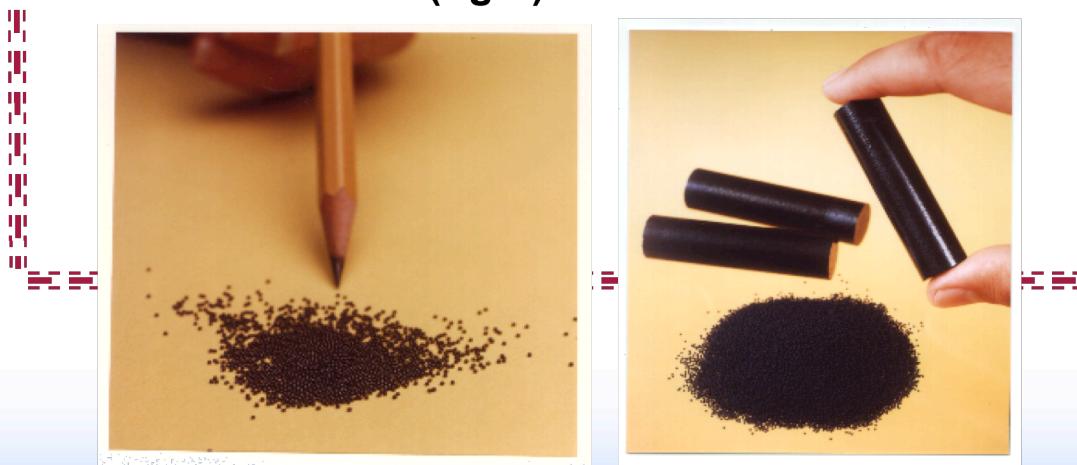
# ***TRISO-coated Particle Fuel***



Pyrolytic Carbon  
Silicon Carbide  
Porous Carbon Buffer  
Uranium Oxycarbide

Uranium Enrichment: 10-20 wt%  
425 mm UCO kernel  
845 mm particle diameter

TRISO Coated fuel particles (left) are formed into fuel rods (center) and inserted into graphite fuel elements (right).



PARTICLES

COMPACTS

FUEL ELEMENTS



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# **LS-VHTR Reactor Core Characteristics**

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- **Advantages**
  - Large thermal power: 2400 MW(th) vs 600 MW(th)
  - LS coolant provides good heat transfer
  - Low pressure (0.5 MPa) vs high pressure (7.12 MPa)
  - Liquid fluoride salts are compatible with graphite at high temperatures (1000 °C)
  - Both LS and He are transparent
  - High boiling point (~1200 °C)

- **R&D Physics**
  - Reactor Core design
  - Salt selection
  - Fuel management
  - Fuel refueling

# **Computer Codes**

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## **1. MCNPX/MCNP5/MCNP4C (Monte Carlo N-Particle)**

- Neutron-photon transport
- Fully explicit 3D geometry models
- Eigenvalues, fluxes and reaction rates
- Continuous-energy neutron cross sections
- ENDF5/6 library data

## **2. ORIGEN2 (Oak Ridge Isotope GENeration)**

- Fuel depletion calculations
- Uses reactor specific cross sections

# *Computer Codes*

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## **3. MOCUP (MCNP-ORIGEN2 Coupled Utility Program)**

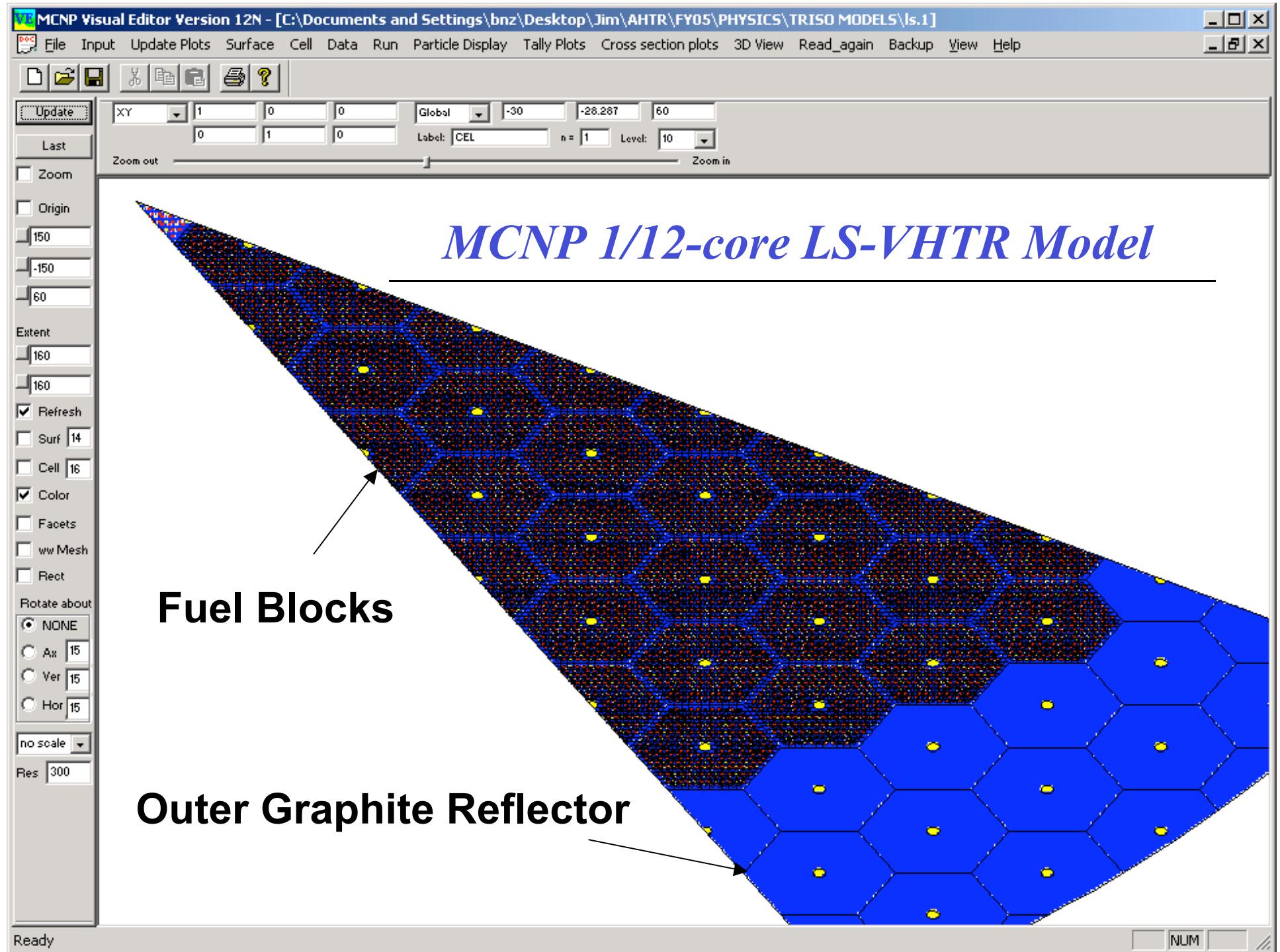
- Utility code
- Link between MCNP & ORIGEN2 inputs/outputs
- Burnup-dependent fuel depletion calculations

## **4. NJOY**

- Nuclear data processing
- Generation of hi-temp U and Pu cross sections

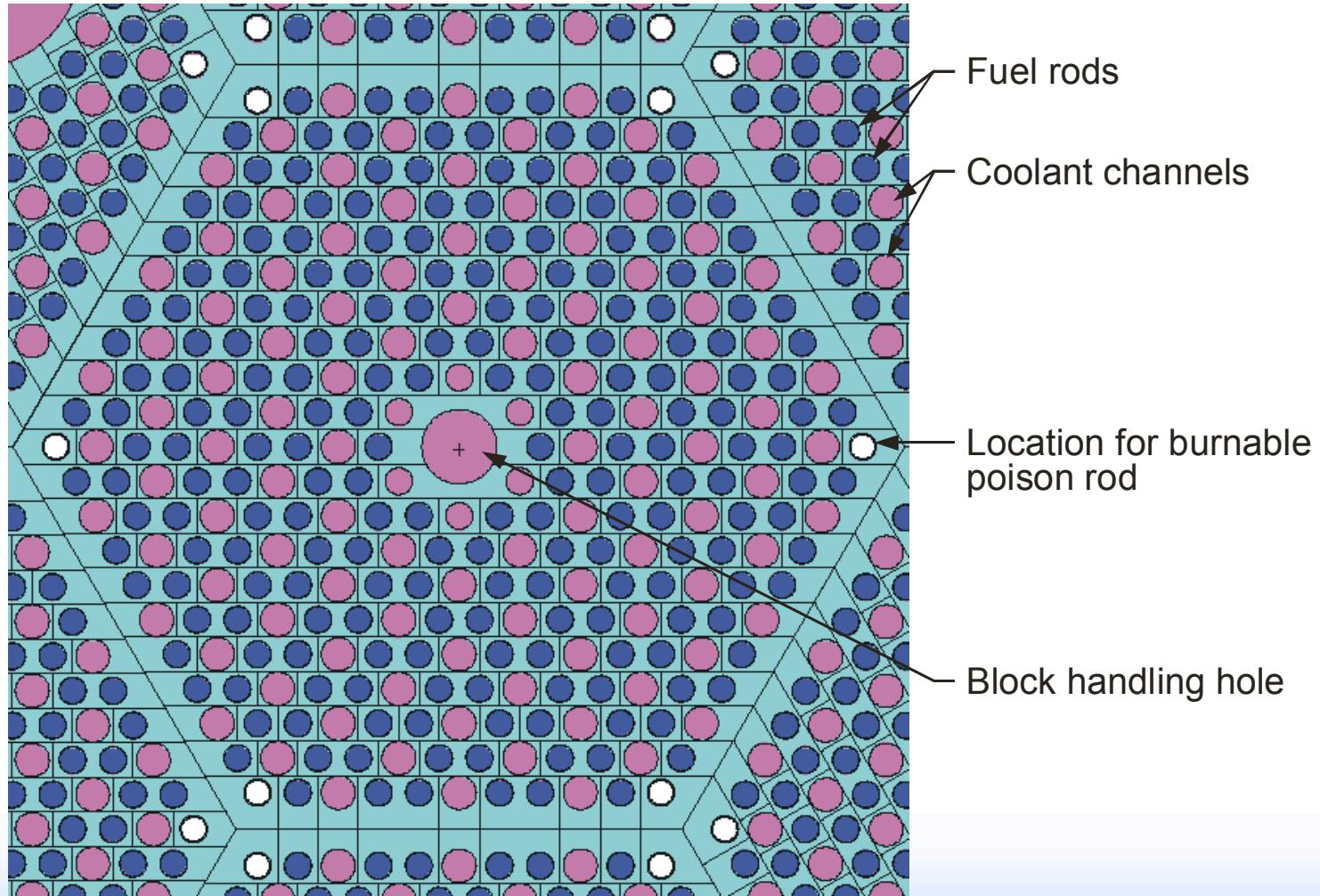


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# *Fuel Block Model Detail*

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# ***LS-VHTR Neutronic Analyses***

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- **Parametric studies to better understand the FLIBE void coefficient of reactivity**
  - Uranium enrichment
  - Coolant channel radius
  - Uranium block loading
  - FLIBE Molar Ratio
  - Other liquid salts

# *Neutronic Analysis*

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- **Assumptions**

- Initial core conditions
- FLIBE ( $2\text{LiF-BeF}_2$ ) coolant ( $950\text{ }^{\circ}\text{C}$ )
- Uniform core loading
- No CR, BP, RSS blocks
- Void coefficients estimated simply as  $Dk$ , or

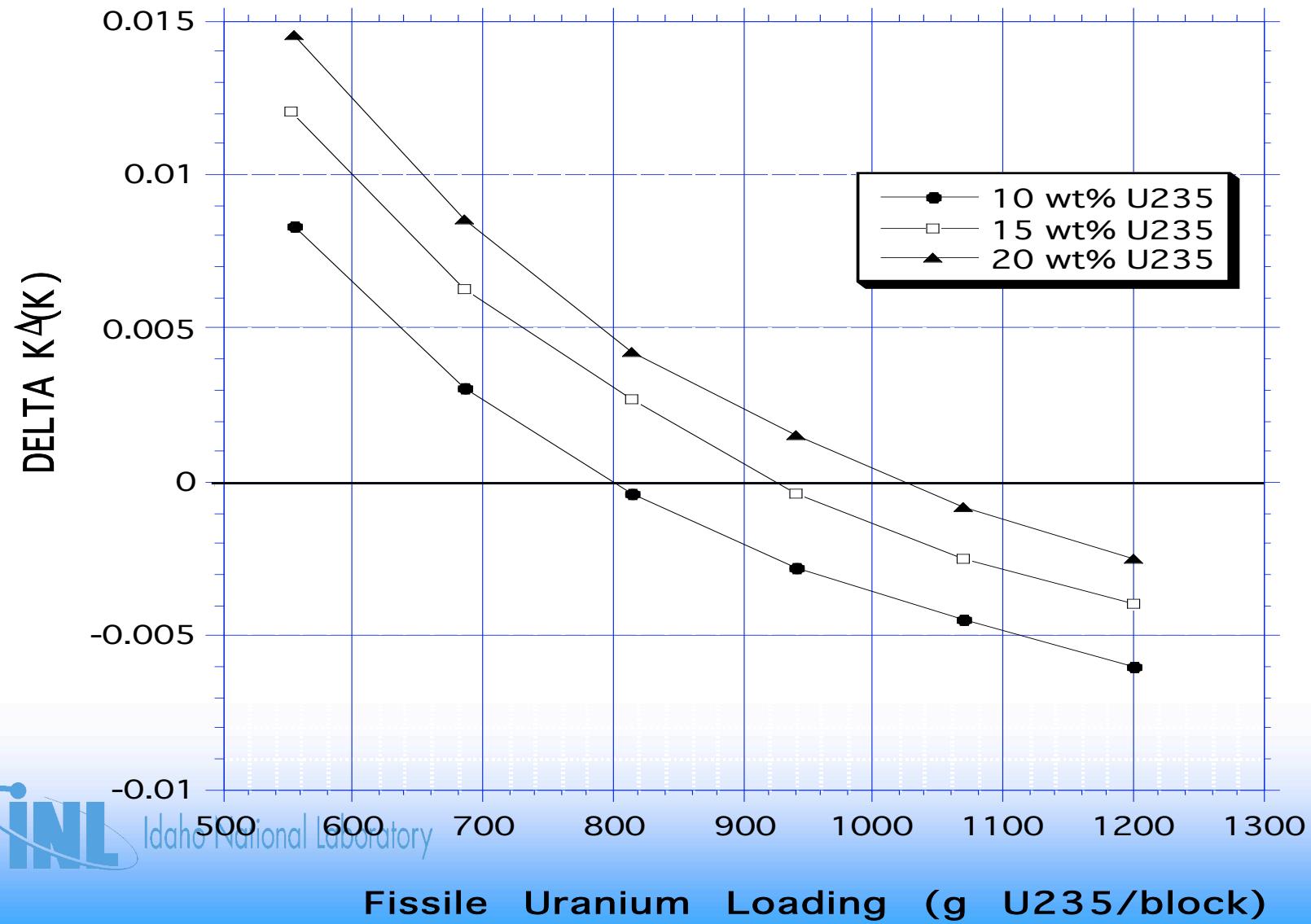
$$Dk = [k_{\text{void}} - k_{\text{FLIBE}}]$$

- 10-20 wt% enrichments
- TRISO particle PF<35%
- 18-month power cycle length



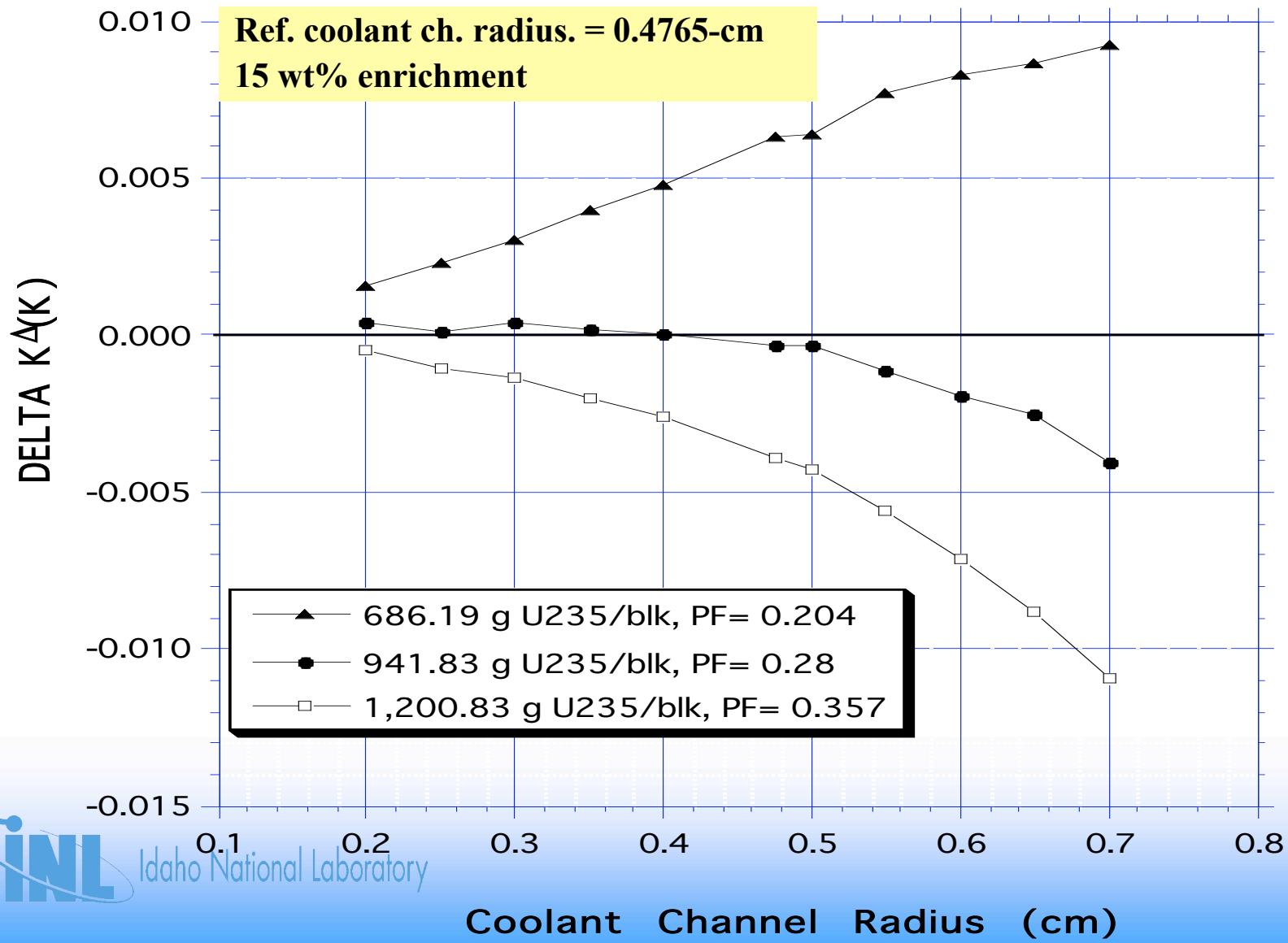
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# ENRICHMENT



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# Coolant Channel Radius



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## ***FLIBE Molar Ratio (1)***

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- Since FLIBE was the only salt to produce a negative VCR for the initial core conditions
- What would be the optimal molar ratio of LiF and BeF<sub>2</sub>?

## ***FLIBE Molar Ratio (2)***

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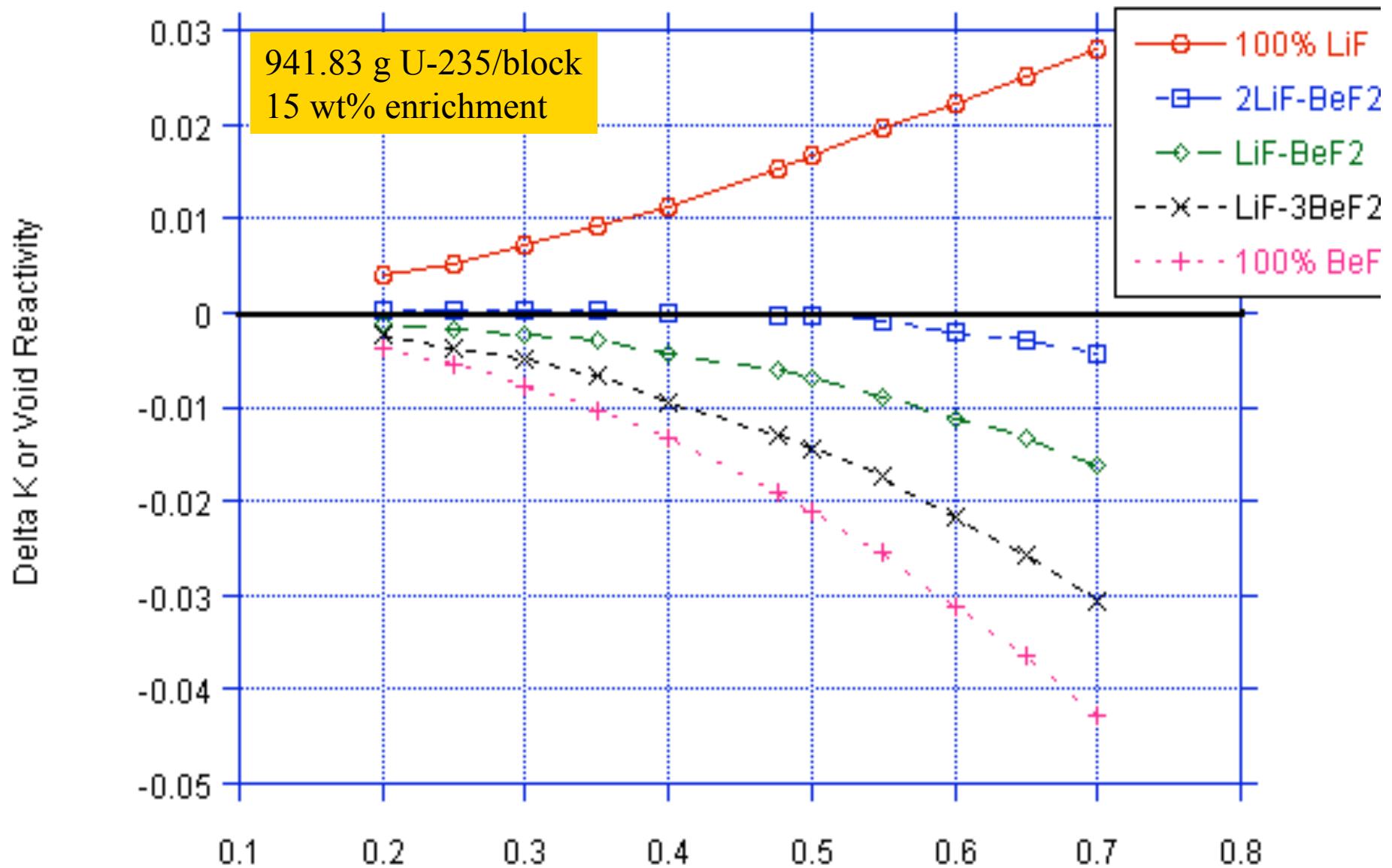
<b>FLIBE Liquid Salt</b>	<b>Approx Molar Ratio</b>	<b>Actual Molar Ratio (%)</b>	<b>Melting Temperature (°C)</b>	<b>Density*</b> <b>(g/cc)</b>
<b>100% LiF</b>	<b>1:0</b>	<b>100:0</b>	--	<b>1.85655</b>
<b>LiF—BeF<sub>2</sub></b>	<b>2:1 (ref)</b>	<b>66.6:33.4</b>	<b>460</b>	<b>1.94298</b>
<b>LiF—BeF<sub>2</sub></b>	<b>1:1</b>	<b>49.8:50.2</b>	<b>363</b>	<b>1.91518</b>
<b>LiF—BeF<sub>2</sub></b>	<b>1:3</b>	<b>25.1:74.9</b>	<b>515</b>	<b>1.91347</b>
<b>100% BeF<sub>2</sub></b>	<b>0:1</b>	<b>0:100</b>	--	<b>1.95716</b>



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\* Density at 750 °C

# ***FLIBE Molar Ratio***



# *Conclusions*

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- **FLIBE currently is the only liquid salt that will produce a negative void coefficient of reactivity with the LS-VHTR reference design under initial core conditions.**
- **FLIBE negativity can be enhanced by:**
  - Heavier loaded prismatic blocks (900-1,200 g U235 per block)
  - Lower enrichments (10 wt% U235)
  - Larger coolant channel (larger FLIBE core inventory)
  - FLIBE molar ratio (increase BeF<sub>2</sub>)
- **Other salts may work, but not neutronically as good as FLIBE**

# *Liquid Salt Coolants*

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- **Leading alternative liquid salt candidates**
  - NaF-BeF<sub>2</sub>
  - LiF-ZrF<sub>4</sub>
  - LiF-NaF-ZrF<sub>4</sub>
  - RbF-ZrF<sub>4</sub>
  - KF-ZrF<sub>4</sub>
  - NaF-BF<sub>4</sub>
  - LiF-NaF-KF
  - NaF-ZrF<sub>4</sub>
- **Factors for LS selection**
  - Melting point
  - Isotopic enrichment
  - Production of tritium
  - Activation
  - Parasitic absorption
  - Neutron moderation
  - Total reactivity coefficient (Doppler, moderator, coolant, etc.)



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